Dry Coal Cleaning in a MagMill

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The MagMill is an innovative technology which combines dry grinding and dry magnetic separation into one unit for a new, practical, environmentally sound and effective approach to removal of ash and pyritic sulfur from coal at a power plant. The primary benefit of the MagMill is driving down the delivered cost of electricity by making a significant savings in the cost of fuel, which can be as much as 60-80% of the operating cost of a coal-fired power plant.

The MagMill removes mineral contaminants from pulverized raw coal at the front end of an electric power plant, eliminating the need to prewash coal. The concept is shown in Figure 1. The MagMill utilizes the ParaMag Magnetic Separator operating in conjunction with a pulverizer where the pulverizer structure is modified to allow the withdrawal of a portion of its internal circulation stream in which mineral contaminants are concentrated. This material is conveyed to a ParaMag Separator for separation of the paramagnetic mineral particles from the diamagnetic coal. The clean coal product of magnetic separation is returned to the mill for further grinding to product fineness. The quality of the pulverizer product is upgraded and the mineral contaminants are rejected as refuse.

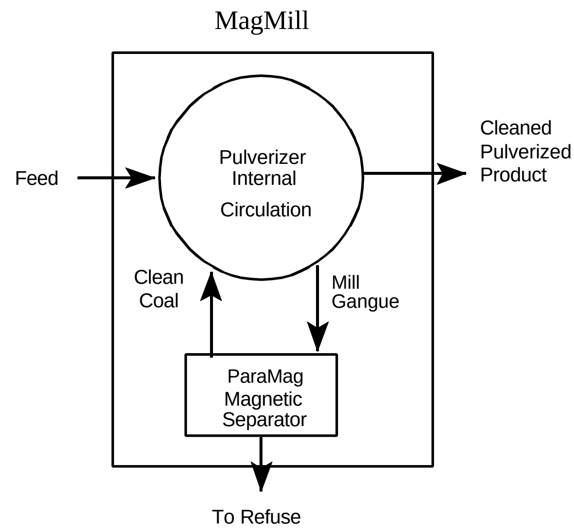

Fig. 1. MagMill Concept

Market Potential

The market for new pulverizers in the U.S. has disappeared, but there is a market for retrofit installations, such as the MagMill, which improve efficiency, reduce emissions, and lower O&M costs. The size of the annual U.S. MagMill retrofit market is estimated to range between $150 million and $220 million with a lifetime of 10-15 years. The annual market for new installations in Asia, where both magnetic separators and new pulverizers can be sold, is estimated to be $250 million over that same time period. In the U.S. there is a site-specific byproduct market where MagMill refuse can be sold to FBC and cement kiln operators. Potential annual revenues from sale of refuse are estimated to be $1.4 million for a typical 1540 MW power station.

The U.S. electricity utility market represents an opportunity to supply magnetic separators for MagMill **retrofit installations** on 199,000 MW generating capacity. This will involve retrofitting 2000 small and older pulverizers which have throughputs averaging about 20 tons per hour (TPH) and approximately 900 large pulverizers with an average throughput of 45 TPH which are located in newer and more efficient power plants. These retrofit installations will employ large magnetic separators scaled to handle entire units at the power station. For example, the average bituminous pulverized coal (pc) fired unit installed in the last twenty years has a capacity of 710 MW; it is supplied by 7 pulverizers each of 45 TPH average throughput. One magnetic separator installed on these mills must be capable of handling 98 TPH of internal pulverizer material. For a typical relatively new 600 MW pc unit firing subbituminous coal, one magnetic separator must handle 122 TPH of internal pulverizer material from 9 pulverizers. Both targets appear realistic for the new technology because of the scalability and economy of the novel ParaMag Magnetic Separator.

Economic Analysis of the MagMill

Use of the MagMill lowers the cost of coal and saves on sulfur emission allowances. After consideration for credits and debits, retrofit installation of MagMills on large mills in the power plant will pay out in less than two years with a 65-87% return on investment depending upon how the refuse is handled. Table I shows that the cost savings possible by displacing washed coal cleaned at the mine with raw coal cleaned at the power plant in a MagMill range from $1.74 to $2.38 per ton of washed coal based on how the MagMill refuse is handled. In Case I, the refuse is disposed at a cost of $3 per ton of refuse whereas in Case II the refuse is sold to FBC or cement kiln operators for $0.6 per million Btu. The net savings of $1.53 per ton of coal is realized by purchasing higher sulfur raw coal and eliminating coal washing at the mine and includes a penalty associated with the higher ash level of the raw coal because approximately 7% more raw coal is required to supply the same heat to the burner as the washed coal. Credit is given for lower sulfur emissions for the MagMill product based upon the current (August, 1997) cost of sulfur emission allowances, $90 per ton SO_2. The analysis assumes a 15 year project lifetime, an inflation rate of 3.5 % per year and uses an internal discount rate of 15%.

Table I
Summary Economic Analysis
Cost Savings: $/Ton of Base Case Washed Coal
MagMill Retrofit to a 1,150 MW Power Station
(2001 Dollars)

	Case I: Dispose MagMill Refuse @ $3/Ton	Case II: Sell MagMill Refuse @ $0.6/MBtu
MagMill Cost Savings:		
Cost of Coal	1.53	1.53
Sulfur Emissions	0.65	0.65
Added MagMill Costs:		
Cost Of MagMill Solids Disposal	-0.23	+0.41
Cost of Ash and LOI Disposal	-0.03	-0.03
MagMill Operating Cost	-0.18	-0.18
Net Cost Savings	1.74	2.38

MagMill Test Program

A test program was carried out to show that a ParaMag dry magnetic separator could be built to operate effectively at the required size and to show that coal with high levels of ash and sulfur contaminants could be extracted from a mill in sufficient quantity to make the technology practical. The work was supported primarily by a U.S. Department of Energy SBIR Phase II Grant, DE-FG05-94ER81764. Matching funding was provided by the Tennessee Valley Authority (TVA), the EPRI Upgraded Coal Interest Group, the Ben Franklin Technology Center of Western Pennsylvania, and Bradley Pulverizer Company. In-kind services were provided by TVA, the Central Illinois Public Service Company (CIPS), and Allegheny Power.

The major tasks of the program were: Scale-Up of the ParaTrap Magnetic Separator, Pulverizer Testing, Coal Testing, Fabrication and Operation of MagMill Demonstration Unit, and Preparation of a Conceptual Level Engineering Evaluation of a MagMill Retrofit Test Unit.

1) **Scale-Up of the ParaTrap Magnetic Separator.** The ParaMag Separator is a continuously operating two stage dry magnetic separator. The first stage, a novel permanent magnet separator, is capable of separating strongly magnetic material down to parts per million. The ParaTrap Separator separates particles which are a million times less magnetic

than iron. The combined unit is called a ParaMag Magnetic Separator. In this program ETCi scaled its alpha prototype 20 Lb/Hr ParaTrap magnetic separator to 2000 Lb/Hr. The beta prototype 2000 Lb/Hr ParaTrap Separator incorporating the new design was built, tested and is in operation at ETCi. The advanced design of the separator permits processing at throughputs of hundreds of tons per hour; cost estimates of commercial size separators (12.5 and 25.5 TPH throughput) were prepared for use in Task 5.

2) **Pulverizer Testing.** In this task measurements of air and particle flow in the internal circulation of on-line, operating pulverizers were made at three power plants: Allegheny Power's Armstrong Power Station in Reesedale, PA, and Fort Martin Power Station in Maidsville, WV, and CIPS' Meredosia Power Station in Meredosia, IL. The measurements confirmed the existence of concentrated gangue in the internal circulation of the mills and established conditions for removal of large quantities of this material from the mills. A mill circulation computer model was developed to simulate ash and sulfur reductions expected by magnetic treatment of portions of the circulation.

3) **Coal Testing**. In this survey a variety of coals from throughout the United States were processed through ETCi's dry magnetic separator to determine their response to magnetic separation. More than sixty bituminous and sub-bituminous coals were tested; 45 coals were supplied by the TVA and the remainder by CIPS, Allegheny Power and Pennsylvania coal companies.

As shown in Figure 2 and Table II, the magnetic measurements made on whole coals indicate applicability of the magnetic method to a broad range of American coals. Ash reductions can be achieved for all coals; sulfur reductions are coal specific. The purpose of the survey was to show that coals can be cleaned by dry magnetic separation. However, the response of whole coals to dry magnetic separation does not predict the ash and sulfur reduction potential of the ***MagMill*** technology. In a MagMill, the pulverizer operates as a first stage mineral concentrator so that the mineral contaminants are concentrated in the internal circulation stream. The degree of concentration depends upon the hardness of the mineral component. Iron pyrite is the hardest mineral in coal and its concentration is the greatest in the mill reject steam (internal pulverizer material). The mill feed and the mill reject are not the same material. Relative to the pulverizer feed, the mill reject stream fed to the magnetic separator is concentrated in mineral contaminants.

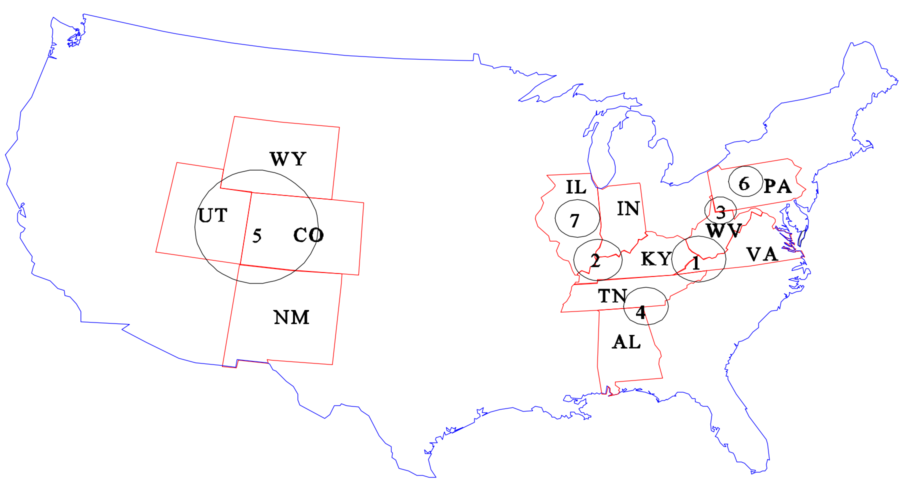

Fig. 2. Results of Survey Measurements

Table II

Comparison of Magnetic Separation Test Results

Region	Number and Sources of Test Coals: Whole Coal	Mill Reject	MagMill Product	Btu Recovery, %: Whole Coal	Mill Reject	MagMill Product	Ash Reduction, %: Whole Coal	Mill Reject	MagMill Product	Sulfur Reduction, %: Whole Coal	Mill Reject	MagMill Product
1	14			89			31			4		
2	23	1	1	87	91	91P	32	31	21P	7	37	45P
3	5	2	2	96	91	98P	20	28	17P	6	37	31P
4	1			82			26			5		
5	7			90			26			7		
6	5	2	2	88	91	96M	37	40	22M	14	37	23M
7	3			85			17			8		
Average % Reductions				88	91	95	27	33	20	7	37	33

P-Projected
M-Measured

The performance of the magnetic separator in rejecting ash and sulfur from the two streams is compared in Table III. The coals are a coherent series ranging from raw to blended to washed. All coal is from EXXON's New Monterey No.1 Mine in Central Illinois. It is apparent that separation of sulfur is **much** better for the mill circulation stream than for the mill feed.

Table III
Magnetic Separation Results for Mill Feed and Mill Circulation Samples
Meredosia Power Station, New Monterey No. 1 Mine Coal

	<----- Magnet Feed ----->		<-------------- Magnet Product -------------->		
	Ash (Wt.%)	Sulfur (Wt.%)	Btu Recovery (%)	Reductions (%) Ash	Sulfur
Mill Feed	25.25	1.26	82.5	40.05	0.33
Mill Circulation	33.64	11.45	86.3	30.16	19.14
Mill Feed	18.36	1.22	83.3	34.49	4.74
Mill Circulation	18.86	16.85	89.1	32.90	44.91
Mill Feed	12.27	1.18	87.7	23.68	5.11
Mill Circulation	11.10	2.26	88.4	23.99	33.40

Ash does not concentrate in the mill refuse stream for this coal as it does for others because the coal contains a relative large proportion of clay minerals which are soft.

ETCi has developed a computer model to simulate the performance of a MagMill. The results of the simulation for the ABB CE Raymond 633 mill at Meredosia is presented in Table IV. The simulation of separation of the relatively soft ash-forming minerals falls in line with the survey measurements as is expected. Simulation of the MagMill performance in separation of sulfur, however, is significantly different. The range of sulfur reductions observed for MagMill internal pulverizer material for coals with feed sulfur in the 1% to 2% range is 25% to 45, compared to -10% to +10% for the survey measurements. It is obvious that MagMill performance cannot be predicted from the survey measurements.

Table IV
Simulated MagMill Performance

Meredosia Generating Station, New Monterey No.1 Coal

<-- Mill Feed -->		<------------ Mill Reject ----------->					<------ MagMill Product ------>	
		Concentration		Concentration		Btu	Concentration	
Ash	Sulfur	Wt.%		Ratio		Recovery	Wt.%	
(Wt.%)	(Wt.%)	Ash	Sulfur	Ash	Sulfur	%	Ash	Sulfur
23.25	1.11	30.42	3.40	1.3	3.1	91.4	18.46	0.61*
15.42	1.11	17.43	3.58	1.1	3.2	96.8	13.80	0.61*
10.55	1.20	12.81	2.05	1.2	1.7	92.2	9.55	0.93
8.45	1.93	11.48	4.46	1.4	2.3	97.4	7.38	1.39

*Organic sulfur content in the mill feed coal.

4) **MagMill Demonstration Unit.** An alpha prototype 200 Lb/Hr MagMill has been built and is in operation at ETCi. It is used to test coals and to demonstrate the concept to utility personnel and other interested parties. This unit, which combines a hammermill and ETCi's 200 Lb/Hr ParaTrap magnetic separator, is instrumented for continuous production of nominal minus 200 mesh coal. It is inerted with a nitrogen blanket for safety. Parameters such as production rates, mill circulation withdrawal rate, etc., can be measured and controlled.

5) **Conceptual Level Engineering Evaluation of MagMill Retrofit Test Units.** An engineering evaluation of the cost to install and operate MagMill retrofit ***test*** units at CIPS's Meredosia plant and at Allegheny Power's Ft. Martin plant was prepared by the Technology and Consulting Group at the Bechtel Corporation of San Francisco, CA.

ETCi modified the equipment lists and cost estimates prepared by Bechtel for the ***test*** units to make an estimate of the capital and operating costs of ***commercial*** MagMill retrofit units installed at the Meredosia and Fort Martin plants. This estimate has been incorporated in the Bechtel report and is summarized in Table V. Figure 3 is a generic flow sheet illustrating the level of complexity needed for a commercial MagMill; the commercial installation is much less complex than a test unit.

The costs, as shown in Table 5, for the Meredosia and Fort Martin installations are for one magnetic separator treating the internal pulverizer material from one mill. The cost for the hypothetical 1150 MW station is for two separators each handling 5 pulverizers. It is apparent that there is an economy of scale. It derives from the scalability of the magnetic separator.

Waste disposal costs are included in the operating costs. In some cases, the MagMill refuse can be sold. The concentrations of ash, sulfur, Btu and iron in the refuse depends upon how the MagMill is operated.

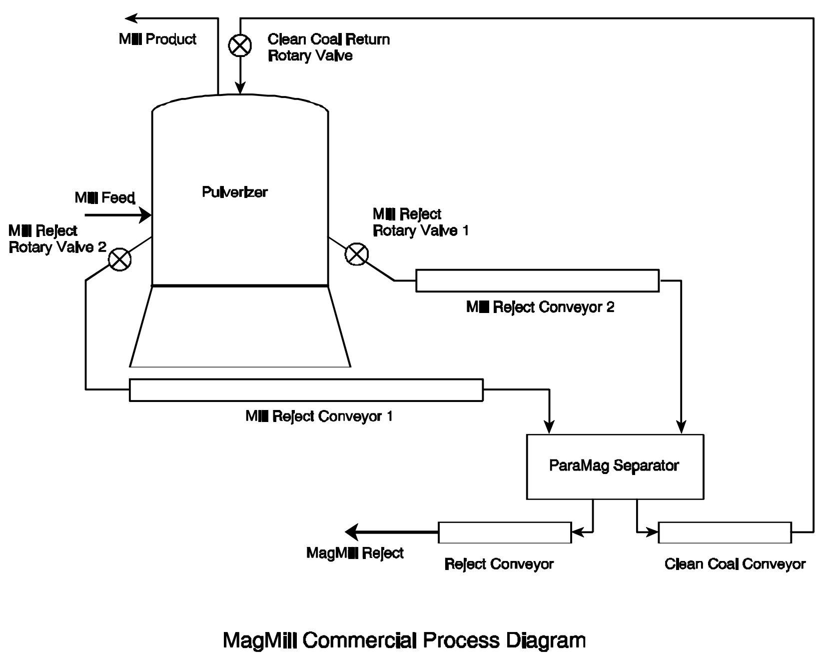

Fig. 3. Generic Process Flow Sheet for the MagMill

Table V
Estimate of Capital and Operating Costs for
Commercial Retrofit ParaMag Magnetic Separators

	Meredosia	Ft. Martin	1150 MW
Number of Pulverizers	1	1	10
Pulverizer Throughput, TPH	12.5	51	45
Number of Magnetic Separators	1	1	2
Magnetic Separator Throughput, TPH	4.2	17	68.3
Capital Charge, $			
Cost of Magnetic Separator(s)	$260,000	$660,000	$5,200,000
Cost of Retrofit	$200,000	$280,000	$1,500,000
Total Capital Charge	$460,000	$940,000	$6,700,000
Operating Charge, $/T mill feed			
	<..................$/T Mill Feed..................>		
Labor	$0.25	$0.10	$0.02
Maintenance, 5% of Total Capital	$0.21	$0.11	$0.08
Electricity	$0.04	$0.03	$0.03
Cooling Water	$0.02	$0.02	$0.02
Waste Disposal	$0.26	$0.25	$0.23
Total Operating Cost	$0.78	$0.51	$0.38